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The challenge of hyperon polarization

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Session 3

Λ-polarization in $pp \to \Lambda X$ (experiment)

Heller, E8

Bravar, E704

- negative and energy independent
- grows linearly with x_F for $p_\perp > 0.8$ GeV/c
- $p_\perp$ independent for $0.8 < p_\perp < 3.5$ GeV/c
- A_N and D_{NN} show similar $p_\perp$ dependence

Λ – polarization is not understood in pQCD

Felix; Soffer; Liang Zuo-tang, Boros

◇ A straightforward collinear factorization
– very small P_Λ

◇ Modifications of simple pQCD

$$P_\Lambda \sim 1/p_\perp$$

Qiu, Sterman; Efremov, Teryaev;
Kanazava, Koike;
Brodsky, Hwang, Schmidt

◇ Role of $k_\perp$–effects

$$P_\Lambda \sim k_\perp/p_\perp$$

polarizing fragmentation functions

Sivers; Collins; Kochelev;
Anselmino, Boer, D'Alesio, Murgia;
Buskulic, ALEPH Coll.

The models

◇ confinement (Lund, Thomas precession)

◇ chiral symmetry breaking

Troshin, N.T.

– chirality is broken by the vacuum

$$\langle 0|\bar{\psi}\psi|0\rangle \neq 0$$

– generates quark masses:

$$m_U = m_u - 2g_4\langle 0|\bar{u}u|0\rangle - 2g_6\langle 0|\bar{d}d|0\rangle\langle 0|\bar{s}s|0\rangle.$$

NJL

Bernard, Jaffe, Meissner

massive quarks – quasiparticles

$$\langle U|\bar{s}s|U\rangle/\langle U|\bar{u}u + \bar{d}d + \bar{s}s|U\rangle \sim 0.1 - 0.5$$

– scale $\Lambda_\chi \simeq 4\pi f_\pi \simeq 1$ GeV

Nonperturbative hadron – constituent quarks
+ quark condensate

Spin of constituent quark

$$J_U = 1/2 \;=\; J_{u_v} + J_{\{\bar{q}q\}} + \langle L_{\{\bar{q}q\}} \rangle = 1/2 + J_{\{\bar{q}q\}} + \langle L_{\{\bar{q}q\}} \rangle .$$

Estimate: $\langle L_{\{\bar{q}q\}} \rangle \simeq 0.4$

associated with the orbital angular momentum (cloud quarks rotate coherently)

Orbital motion of quark matter — origin of the asymmetries in inclusive processes

Interaction of hadrons

- overlapping and interaction of peripheral clouds, condensate excitation
- quasiparticles
- mean field

Hyperon production

- Recombination (Q + S), soft interactions

- Scattering Q, hard interactions ($r < R_Q \sim 1/\Lambda_X$)

It is short distance dynamics which leads to production of polarized Λ's.

Mechanism for Λ polarization

Polarization of strange quark results from

- multiple scattering of Q

$$\mathcal{P}_Q \propto -I\frac{m_Q g^2}{\sqrt{s}} \sim const$$

Szwed

$$m_Q \sim m_h/3, \quad I \sim \sqrt{s}$$

- correlation between s-quark polarization and polarization of the parent Q

$$\langle L_{\{\bar{q}q\}}\rangle^{\mathcal{P}_Q(x)} = \mathcal{P}_Q(x)\langle L_{\{\bar{q}q\}}\rangle$$

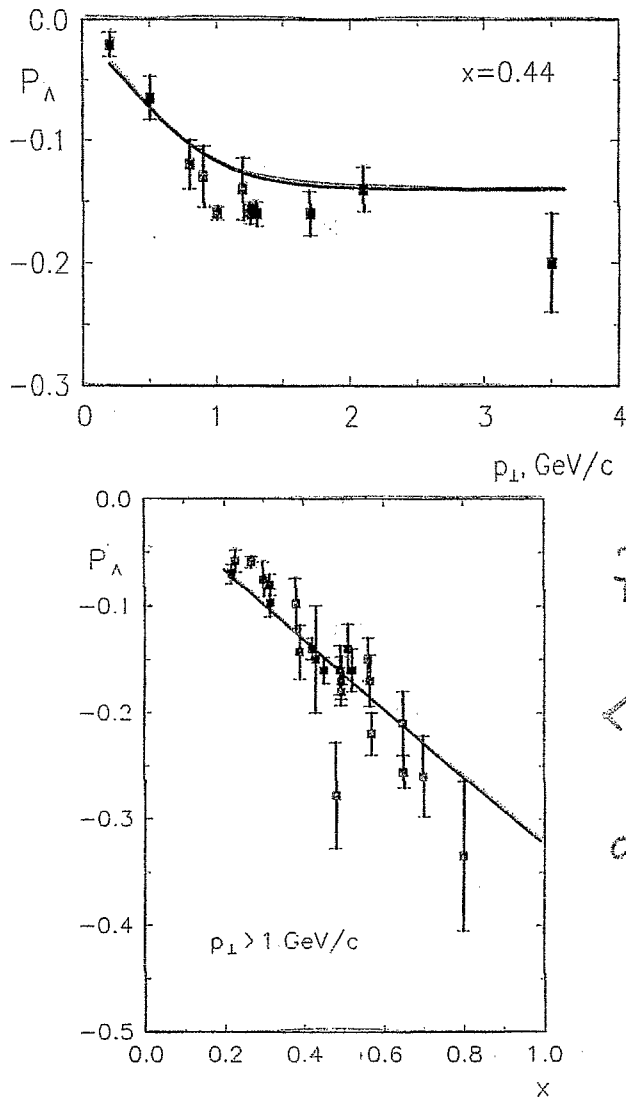
$$L_{s/Q} = \alpha\mathcal{P}_Q(x)\langle L_{\{\bar{q}q\}}\rangle$$

$$P(s,x,p_\perp) = \sin[\mathcal{P}_Q(x)\alpha\langle L_{\{\bar{q}q\}}\rangle]\frac{R(s,x,p_\perp)}{[1+R(s,x,p_\perp)]},$$

$$R(s,x,p_\perp) \gg 1 \quad \text{at} \quad p_\perp > \Lambda_\chi$$

$$P(s,x,p_\perp) = \sin[\mathcal{P}_Q(x)\alpha\langle L_{\{\bar{q}q\}}\rangle]$$

- vanishing polarization for $p_\perp < \Lambda_\chi$
- P_Λ increase in the region of $p_\perp \simeq \Lambda_\chi$
- $p_\perp$ independent polarization for $p_\perp > \Lambda_\chi$



$R(s, x, p_\perp)$

$m = 0.2$ GeV

$P_Q(x) = P_Q^{max} \cdot x$

$\langle L_{1993} \rangle \simeq 0.4$

$\alpha = 0.2$

Figure 1: Transverse momentum and x dependence of P_Λ.

$R(s, x, p_\perp) = C(x) \exp\left(\frac{p_\perp}{m}\right) / (p_\perp^2 + A_x^2)^2$

this function R implies typical behaviours of cross-sections of hard and soft processes

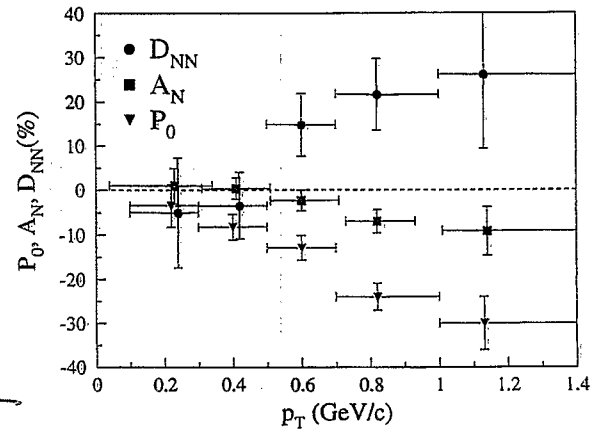


Fig. 2

Bravar

Figure 11: Spin observables in $p \uparrow p \to \Lambda^0 + X$ at 200 GeV/c from FNAL.

The large positive D_{NN} values indicate a sizable spin transfer (as large as 30 %) from the incident polarized proton to the outgoing Λ^0. Large spin transfers in hyperon production have been also observed in inclusive Ξ^- and Ω^- production by a neutral beam containing also transversely polarized Λ^0's and Ξ^0's [42,43]. Unfortunately, the amount of this spin transfer has been never quantified. The spin transfer in the latter reactions is more easily interpreted in quark models, since a polarized valence *strange* quark from the incoming polarized hyperon is transferred to the outgoing hyperon which is also polarized, while in the former process ($p \uparrow p \to \Lambda^0 + X$) there are no polarized valence *strange* quarks in the incident polarized proton.

Figure 11 is my favorite plot concerning *spin effects* in inclusive Λ^0 production. It summarizes the 3 spin observables discussed so far. All data shown were taken in the same kinematical region and simultaneously (experiment E704 at FNAL) [41], therefore allowing for a straightforward comparison of P_0, A_N, and D_{NN}. All 3 spin parameters show a similar p_T dependence, but with different signs and magnitudes, in which the asymmetries increase with p_T:

$$P_0 \sim -D_{NN} \sim \frac{1}{3} A_N < 0 \,.$$

In most of the quark models proposed so far to explain the Λ^0 polarization, the Λ^0 spin is carried by its constituent *strange* quark while the *ud* di-quark is in a spin and isospin singlet state (SU(6) wave functions). Therefore, no correlation with the incident proton polarization is expected in Λ^0 production, since

- D_{NN} is positive since P_Λ has the same sign as $\mathcal{P}_Q$

Fig. 2 • Similarity of $p_\perp$ dependencies

Experimental prospects

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$$p_{\uparrow,\rightarrow} + p_{\uparrow,\rightarrow} = \Lambda_{\uparrow,\rightarrow} + X.$$

$(n, n, n, 0)$ and $(l, l, l, 0)$

- significant P_Λ at RHIC energies

- a signal for QGP formation (chiral symmetry restoration)
  $P_\Lambda \longrightarrow 0$ with centrality increase

  Angert; Panagiotou; Ayala, Cuautle, Herrera, Montano; Troshin, N. T.